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Structure and Hysteresis of Patterned Soft-Magnetic Structure

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Structure and Hysteresis of Patterned Soft-Magnetic Structure

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Patterned films produced by photolysis. The most commonly used method for the fabrication of arrays of isolated magnetic features is lithography [1–3], but recently more advanced methods have been introduced. These techniques include fabrication using chemical vapor deposition in a scanning tunneling microscope [4], an atomic force microscope [5], or a scanning transmission microscope [6].

Here we report the fabrication and investigation of patterned nickel films using a different and somewhat unconventional approach: laser assisted organometallic chemical vapor deposition (OMCVD). The process involved in this technique is the photolysis of organometallic molecules under exposure to a certain radiation with a specific wavelength. The main advantages are that this method uses a single-step fabrication process, the chemical contamination of the deposited films is very low, and that this technique is compatible with ultra-high vacuum technologies. The features grow with rhombohedrally distorted f.c.c. (111) texture and exhibit in-plane anisotropy.

Experimental. Selective OMCVD was carried out in an ultra high vacuum chamber with a base pressure maintained at 5×10^{-10} Torr. Nickelocene ($Ni_2(C_5H_5)_2$), a molecule that contains a Ni atom sandwiched between two C_5H_5 rings, was used as a source compound. The incident radiation for photolysis was supplied by a commercial (Molectron) nitrogen laser with a wavelength of 337 nm (3.69 eV) and focused by a quartz lens onto the Si(111) substrate. During irradiation, mass components were detected by a quadrupole mass spectrometer operated in the pulse counting mode. A metal grid with spacing of 20×20 μm^2 was used to restrict the illumination as a close contact mask, or act as a diffraction grating. The diffraction effects of the single wavelength laser radiation on the holes of the mask give us the possibility of changing the shapes of the Ni features deposited on a Si(111) substrate [7]. The dimensions of the features range between 8 and 30 μm, and the thickness between 0.3 and 1 μm as can be seen in the inserts of Figure 2. The films were characterized using X-ray diffraction and MFM. The experimental hysteresis loops were obtained in an alternating gradient force magnetometer (AGFM).

To identify the crystalline structure of the deposited structures we used X-ray diffraction measurements. Figure 1 shows the unique peak observed in a high angle θ–2θ scan. The peak is also slightly shifted from its place, indicating that the films are probably rhombohedrally distorted, compressed by about 1% perpendicular to the film.

Magnetic behavior. Measured hysteresis loops and a theoretical fit are shown in Figure 2. As expected for inhomogeneous structures, the loop shape is very different from rectangular Stoner-Wohlfarth type loops. The ultimate reason is that the coherent rotation model is unable to describe magnets larger than 20 nm, because the interatomic exchange responsible for coherency is a strong but short-range interatomic force [8, 9]. As encountered in other thin-film structures, for example in Fe(110) sesquilayers [10], the magnetization processes responsible for hysteresis are incoherent, but the low remanence shows that the remanent magnetization configuration is close to the ground state [11].

The theoretical modeling of the loops, corresponding to the solid lines in Figure 2, will be published elsewhere [11]. Essentially, the loop shape and the coercivity are considered as separable quantities. MFM studies [12] reveal that the remanent magnetization state is strongly nonuniform. This implies the existence of domain walls and indicates that the coercivity is due to domain-wall pinning. For squares, circles and bars the experimental coercivities are 7.1, 7.7, and 13.9 mT, respectively. The analysis of the problem [11] indicates that the leading coercivity mechanism is domain-

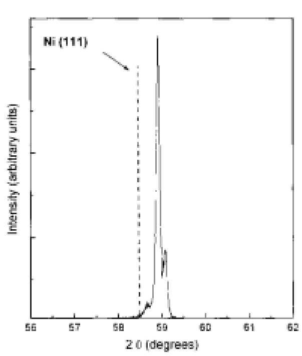

Figure 1. High angle X-ray diffraction (λ = 1.54 Å) for a patterned Ni thin film deposited on Si(111), acquired in a sealed tube Rigaku diffractometer. The position of rhombohedrally distorted f.c.c. (111) peak is indicated. The rhombohedral *c/a* ratio is reduced by about 1% due to strain

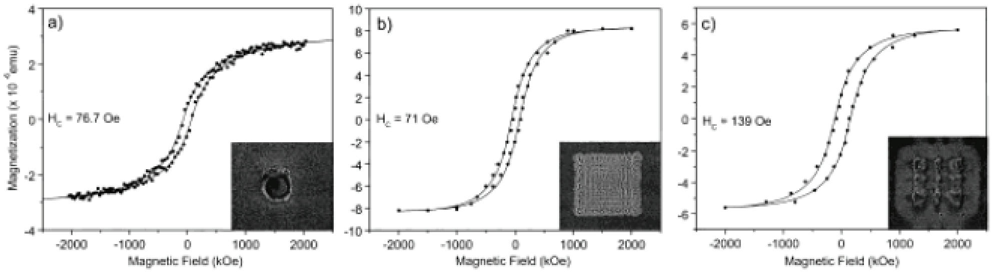

Figure 2. Scanning electron micrographs and in-plane hysteresis loops of Ni features: a) circle having a diameter of 8 mm; b) 20 × 20 mm square, and c) 3 × 17 µm bars. The thickness *t* of the films is 500 nm. The solid lines are fits obtained from the theoretical model

wall pinning by magnetic surface charges, whereas the differences between the samples are associated with macroscopic demagnetizing fields. The random surface charges are ascribed to film thickness fluctuations rather than to chemical disorder or to atomic defects, although local mechanical stresses may be non-negligible [11].

From Figure 2 we see that the features consist of morphological subfeatures having a size of the order of 1 µm, and both MFM [12] and Kerr microscopy [6] show that these subfeatures are relevant to the magnetic response. The basic idea of the loop-shape modeling is to consider the subfeatures as quasiindependent. This assumption is motivated by Figure 2, which shows that — aside from the demagnetizing-field dependence of the coercivity — there is no significant dependence of the hysteresis-loop shape on the sample shape. On a subfeature scale, there are domain walls easily moving in the combined Zeeman and magnetostatic self-interaction fields. To calculate the loop shape, a simple but morphologically well-defined subfeature model is used [11]. Due to the domain-wall motion there are inhomogeneous demagnetizing fields, but the calculation shows that these demagnetizing fields can be mapped onto a renormalized demagnetizing factor. Interestingly, the corresponding demagnetizing factor expression is negative, of the order of 0.15. Note that a similar effect exists in inhomogeneous nanostructures [13], but in that case it reflects the direct competition of exchange and anisotropy on a length scale of about 10 nm rather than domain-wall motion on a µm scale. Since the thickness of the structures is known, about 500 nm, it is possible to deduce the subfeature size from the magnetization curves. The results, 1 to 2 µm, are in fair agreement with the AFM images.

Conclusions. We have analyzed the magnetism of Ni features deposited on nonmagnetic substrates using a novel method: laser assisted chemical vapor deposition. Both coercivity and loop shape are determined on a scale of order 1 mm, which is much smaller than the lateral size of the features. The magnetization curves are fitted to a simple substructure morphology model, although there is secondary dependence of the coercivity on the shape of the structures.

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